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# The Investigation of Strength and Water Absorption of Self-compacting Concrete by Inclusion of Metakaolin and Calcined Kaolin

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**ABSTRACT**

In this study, commercially available high reactivity Czech metakaolin and calcined impure local kaolin were used for production Self Compacting Concrete (SCC) samples and some hardened properties of these concretes have been investigated. Four types of SCC mixtures were prepared with 0%, 5% and 10% replacement level of Metakaoline and calcined kaolin with including control mixture without any mineral admixtures. Only Portland Cement (PC) was used for production of the control mixture and this mixture was produced with the purpose of comparison. The highest compressive strength value was obtained as 83.5 MPa with 10% replacement level of Metakaolin. The lowest water penetration depth was also calculated as 3.5 mm with 10% replacement level of Metakaolin. The compressive strength and water penetration tests showed that the best strength and durability performance values obtained from mixtures with 10% replacement level of Metakaolin.

**Keywords:**
Self compacting concrete; Czech metakaolin; Calcined kaolin.

## INTRODUCTION

Self-Compacting Concrete (SCC) is a special type of high-performance concrete with high fluidity and workability properties due to its lower water to cement ratio which leads to rapid strength development and high durability performances. This special concrete fills the framework without any vibration process and it can be easily placed in the dense reinforcement [1, 2]. Additionally, SCC shows better performances in terms of segregation and bleeding. Nowadays it becomes one of the most popular construction materials [3, 4].

The researchers are focused on fresh and hardened properties of the SCC [5, 6]. Filling ability, passing ability, and segregation resistance are the main fresh properties of SCC. Slump flow test, V-funnel test, J-ring test and Orimet test are used for determination of filling abilities of SCC. For determination of the passing ability of SCC L-box test and J-ring tests are used and for determination of segregation resistance of SCC sieve stability test and penetration test are used [7]. Compressive strength, tensile strength, sorptivity, modulus of elasticity, creep, shrinkage, freeze-thaw resistance, permeability and water absorption are the main hardened properties of SCC. Scientists carried out many experimental studies for determination of these hardened properties [8, 9, 10, 11, 12].

An experimental analysis has been applied to calculate hardened properties of SCCs those contains high-reactive Czech Metakaolin (MK) and commercially available Turkish local Calcined Kaolin (CK) in the present study. The compressive strength and water absorption tests were used to define strength and durability properties of SCC mixtures. The development of strength and durability features of SCCs were observed.

## MATERIALS USED IN THE EXPERIMENTS

In the experimental analysis, SCC with MK and CK were produced for determination of the hardened properties of SCC. In addition, the control mixture of SCC with Portland cement has been used to make a comparison.

### Metakaolin (MK)

MK is a thermally activated cementitious material obtained by the calcination of kaolinitic clay [13, 14].

Kaolin is quite stable in normal atmospheric conditions. However, kaolin heats up to 650-900 C° during calcination process and it loses approximately 14% of its mass inbound hydroxyl ions and then MK is formed. MK utilized in the experimental analysis was obtained from the Czech Republic. It has a whiteness value (Dr. Lange) of 87 and a specific gravity of about 2.60. Its specific surface area (Nitrogen BET Surface Area) is 18000 $cm^2/g$. Chemical, physical and mineralogical properties of MK is shown in Table 1.

## Calcined Kaolin (CK)

Calcined kaolin (CK) is an another widely used material after 1990's to improve the properties of concrete [15, 16]. CK is used as cement replacement material for improving properties of SCCs at different replacement levels. CK was obtained from a quarry located in Balıkesir province (Sındırgı district – Düvertepe village). This kaolin was subjected to 3 hours calcination process before being used in the experimental study. Chemical, physical and mineralogical properties of calcined impure kaolin (CK) is shown in Table 1.

**Table 1.** Chemical, physical and mineralogical properties of CK and MK

| Type | Compound | CK | MK |
|---|---|---|---|
| Chemical Properties (%) | Cao | 2.22 | 0.5 |
| | $SiO_2$ | 69.78 | 53 |
| | $Al_2O_3$ | 24.16 | 43 |
| | $Fe_2O_3$ | 0.69 | 1.2 |
| | MgO | 0.89 | 0.4 |
| | $TiO_2$ | 0.48 | 0.8 |
| | LOI | 0.73 | 0.4 |
| Phisical Properties | Specific Gravity | 2.6 | 2.6 |
| | Fineness ($cm^2/g$) | 7430* | 18000* |

*BET (Brunauer–Emmett–Teller) nitrogen adsorption method

## Cement

PC 42.5R (CEM I 42.5R) type cement was used for the production of SCCs. It has a specific gravity of 3.13 and Blaine fineness of 3380 $cm^2/g$. The technical details and chemical composition of the cement are shown in Table 2 and Table 3.

**Table 2.** Technical details of CEM I 42.5R

| Property | Unit | Normative Value | Average Value |
|---|---|---|---|
| Water Demand | % | N/A | 28.4-30.0 |
| Initial Setting Time | min | ≥ 60 | 100-180 |
| Compressive Strength (2 days) | MPa | ≥ 20 | 27.5-33.5 |
| Compressive Strength (28 days) | MPa | ≥ 42.5, ≥ 62.5 | 54.0-59.0 |

## Coarse and Fine Aggregate

Coarse and fine aggregates used in the experiments were obtained from a local limestone quarry. The gradation of aggregates is closed to Fuller's curve as shown in Fig. 1. The properties of the fine and coarse aggregates are presented in Table 4.

**Table 3.** Chemical composition of the CEM I 42.5R

| Compound | % |
|---|---|
| CaO | 63.6 |
| $SiO_2$ | 19.49 |
| $Al_2O_3$ | 4.54 |
| $Fe_2O_3$ | 3.38 |
| MgO | 2.63 |
| $SO_3$ | 2.43 |
| $K_2O$ | 0.72 |
| $Na_2O$ | 0.22 |
| LOI | 2.99 |

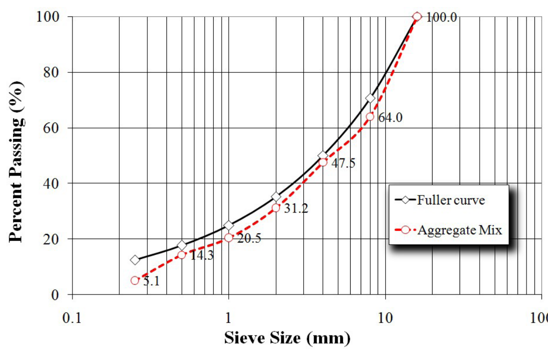


**Figure 1.** Aggregate grading curves

**Table 4.** The properties of the fine and coarse aggregates

| Property | Fine Aggregate | Coarse Aggregate |
|---|---|---|
| Fineness Modulus | 3.38 | 5.68 |
| Specific Gravity | 2.45 | 2.72 |
| Water Absorption (%) | 0.95 | 0.45 |

## Superplasticizer

A high range water reducing admixture (HRWRA) with a specific gravity of 1.07 and pH value of 5.7 was used in the experimental study to get a consistent workability for SCC mixtures. HRWRA is used in the experimental analysis. It is polycarboxylic ether type water reducing admixture commonly used in SCC production.

## Mix Proportions

In the present study, SCC mixtures with W/B ratio of 0.35 and binder replacement levels 0%, 5% and 10% were produced. The total binder content was 550 kg for 1 $m^3$

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mixture. Portland cement (PC) and thermally treated kaolins, MK and CK, were utilized in experiments. Control mixtures were produced only with Portland cement. Details of the mixes of SCCs are given in Table 5. The concretes were produced to provide a slump flow diameter of 700±20 mm. These properties were obtained by using HRWRA at different percentages.

When the curing time elongates, above 3 days, the mixing percentages of the same type of MK10 concrete mixture values have better compressive strength performance than MK5 concrete mixture values in all curing periods. CK5 mixtures show better performances for 3 and 7 day curing periods in SCCs. However CK10 mixtures show better strength performances in 28 and 56 day curing periods.

**Table 5.** Information of the mix proportions of SCCs

| Type of Calcined Kaolin | Replacement Level (%) | Mix ID | Cement | Calcined Kaolin | Water | Coarse Aggregate | Sand | HRWRA |
|---|---|---|---|---|---|---|---|---|
| None | 0 | Control | 550 | 0 | 192.5 | 790.9 | 750.6 | 7.43 |
| MK | 5 | MK5 | 522.5 | 27.5 | 192.5 | 787.4 | 747.2 | 8.25 |
| | 10 | MK10 | 495 | 55 | 192.5 | 783.4 | 743.5 | 9.35 |
| CK | 5 | CK5 | 522.5 | 27.5 | 192.5 | 787.4 | 747.2 | 8.25 |
| | 10 | CK10 | 495 | 55 | 192.5 | 783.4 | 743.5 | 9.35 |

## EXPERIMENTAL ANALYSIS AND RESULTS

In this study, SCC mixtures with water/binder ratio of 0.35 and binder replacement levels 0%, 5% and 10% were produced. The total binder content was 550 kg for 1 $m^3$ mixture. The concretes were designed to provide a slump flow diameter of 700±20 mm. This was achieved by using HRWRA at varying amounts.

### Compressive Strength

Compressive strength test applied 15x15x15 cm cube specimens according to ASTM C39 / C39M-16b (ASTM, 2016) standard. The test machine has a 3000 kN loading capacity. Cube specimens tested at the ages of 3, 7, 28, and 56 days for determination of compressive strength developments. The age-related compressive strength of the SCCs produced with CK and MK are shown in Table 6 and graphically presented in Fig. 2. It can be clearly observed that the compressive strength values of different mixture types have lower values than the control mix values at the beginning of curing days (3 and 7 days). However, the compressive strength values show an increasing trend after 7 days according to the control mix values. The increase in compressive strength of concrete is due to both microfilling and hydration of mineral admixture with Portlandite (13,14). Control mixtures, SCCs without MK or CK, gain strength by hydration of PC, however MK or CK used SCCs gain strength by both hydration of PC and pozzolanic reactions of MK or CK (14,15).

The highest compressive strength result (83.5 MPa) is achieved with 10% MK after 56 curing days. The second best performance is obtained with 5% MK as 78.4 MPa in 56 curing days.

**Table 6.** Compressive strength (MPa) of the SCC mixtures

| Mixture | Replacement Level (%) | Age (Days) | | | |
|---|---|---|---|---|---|
| | | 3 | 7 | 28 | 56 |
| Control | 0 | 62.2 | 65.4 | 68.6 | 70.2 |
| MK5 | 5 | 60.2 | 64.1 | 75.7 | 78.4 |
| MK10 | 10 | 58.7 | 67.4 | 78.5 | 83.5 |
| CK5 | 5 | 59.8 | 65.6 | 70.6 | 74.8 |
| CK10 | 10 | 53.8 | 63.9 | 74.1 | 77.8 |

CK incorporating SSCs and control mixtures have lower compressive strength values than MK incorporating SSCs. It is mostly due to the fineness level and reactivity level of MK.

### Water Absorption

Water absorption test was applied to SCC specimens according to BS 1881 (Part 122) standard (BS, 1983). The concrete specimens were placed in the drying. After 72 ± 2 hours, specimens were removed from the oven, and then they were allowed to cool at room temperature for

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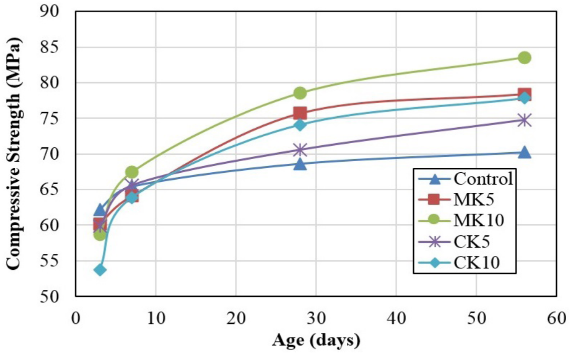


**Figure 2.** Compressive strength values of SCC mixtures

24 ±0.5 h in the dry airtight vessel. All specimens were weighed and immersed in the water-filled tank for 30 ± 0.5 min. At the end of the specified time, they were removed from the water, dried with a dry towel and weighed again. The results tabulated in Table 7 and visualized in Fig. 3. When the results of all concrete samples are taken into account the 10% MK containing SCCs have the least water absorption values as %2.8 and %1.8 by weight for 28 and 56 days. The water absorption values of MK, CK, and Control SSCs are ranged between 1.8-3.3%, 2-3.5%, and 2.8-3.6%, respectively by weight. 5% CK containing SCC absorbed less water than the control sample with a slight difference for 28 days period; however, it absorbed more water than the control sample for 56 days period. The results of 10% CK, %10MK and %5MK containing SCCs have lower water absorption values in both periods of 28 and 56 days. The lowest values were obtained from the control samples in both curing periods.

**Table 7.** Water absorption values of SCCs (% by weight)

| Mixture | Replacement Level (%) | Age (Days) | |
|---|---|---|---|
| | | 28 | 56 |
| Control | 0 | 3.6 | 2.8 |
| MK5 | 5 | 3.3 | 2.5 |
| MK10 | 10 | 2.8 | 1.8 |
| CK5 | 5 | 3.5 | 2.65 |
| CK10 | 10 | 3 | 2 |

## CONCLUSION

In this experimental study, the effect of high reactivity Czech metakaolin and calcined impure Turkish kaolin on hardened properties of self-compacting concrete is analyzed. The following conclusions might be drawn from the findings.

The compressive strength tests showed that the use of MK and CK increase minimum %5 and maximum %19 of the compressive strength values of SCC. After 3 days curing period the compressive strength values of MK5, MK10, CK5 and CK10 mixes have found lower than the control mixes of SCC. The strength improvements have been observed after 7 days curing period and reached the maximum levels at 56 days. The best strength values for all the SCC mixtures (MK5, MK10, CK5, and CK10) were obtained at the end of the 56 days. %10 MK modified SCCs (MK10) show the highest compressive strength performance as 83.5 MPa (%19 increase). The optimum replacement levels of MK and CK were found as 10% in terms of SCC strength development.

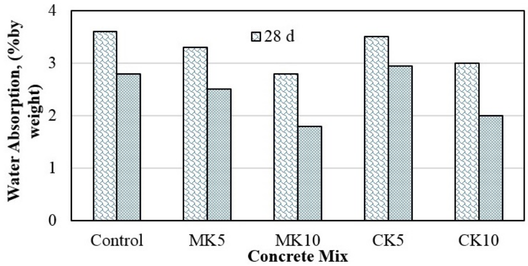


**Figure 3.** Water absorption values of SCC mixtures

The minimum and maximum water absorption values obtained from %10 MK incorporated concrete as 1.8 % by weight in 56 days curing period. Control SCCs mixes have highest water penetration depths for both 28 and 56 days curing periods. %5 replacement levels of MK and CK in SCC showed lower performance than %10 replacement levels.

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